Detector R&D

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P5 Recommendations

Recommendation 4: Maintain a program of projects of all scales, from the largest international projects to mid- and small-scale projects.

Advances in particle physics come from a combination of experimental and theoretical work, as well as from *R&D* for advanced accelerator and experimental techniques.

Recommendation 15: Select and perform in the short term a set of small-scale short-baseline experiments that can conclusively address experimental hints of physics beyond the three-neutrino paradigm. *Some of these experiments should use liquid argon to advance the technology and build the international community for LBNF at Fermilab*.

Recommendation 27: Focus resources toward directed instrumentation R&D in the near-term for high-priority projects. As the technical challenges of current high-priority projects are met, restore to the extent possible *a balanced mix of short-term and long-term R&D*.

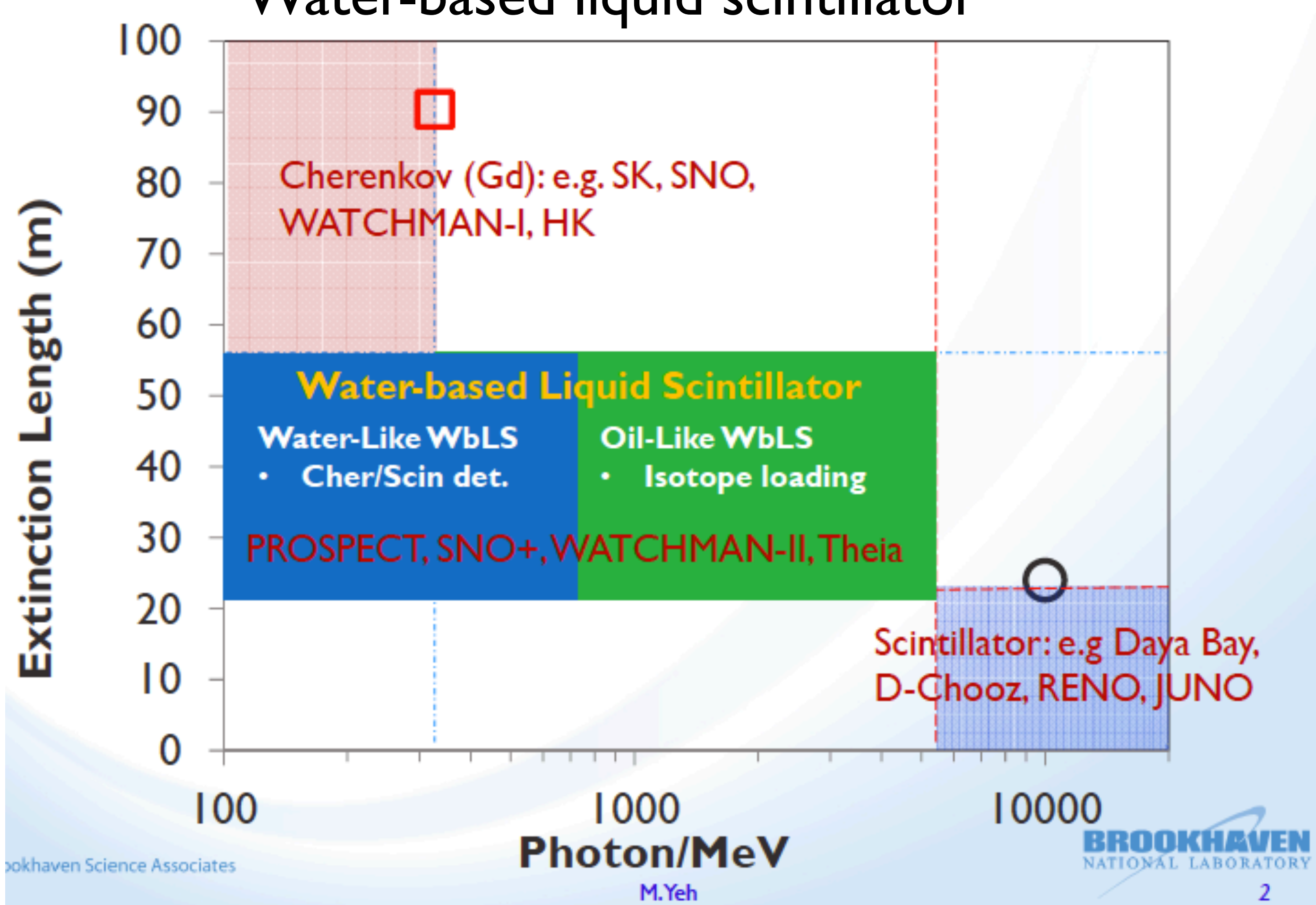
Recommendation 28: *Strengthen university-national laboratory partnerships in instrumentation R&D through investment in instrumentation at universities*. Encourage graduate programs with a focus on instrumentation education at HEP supported universities and laboratories, and fully exploit the unique capabilities and facilities offered at each.

R&D on a portfolio of technologies follow from these recommendations.

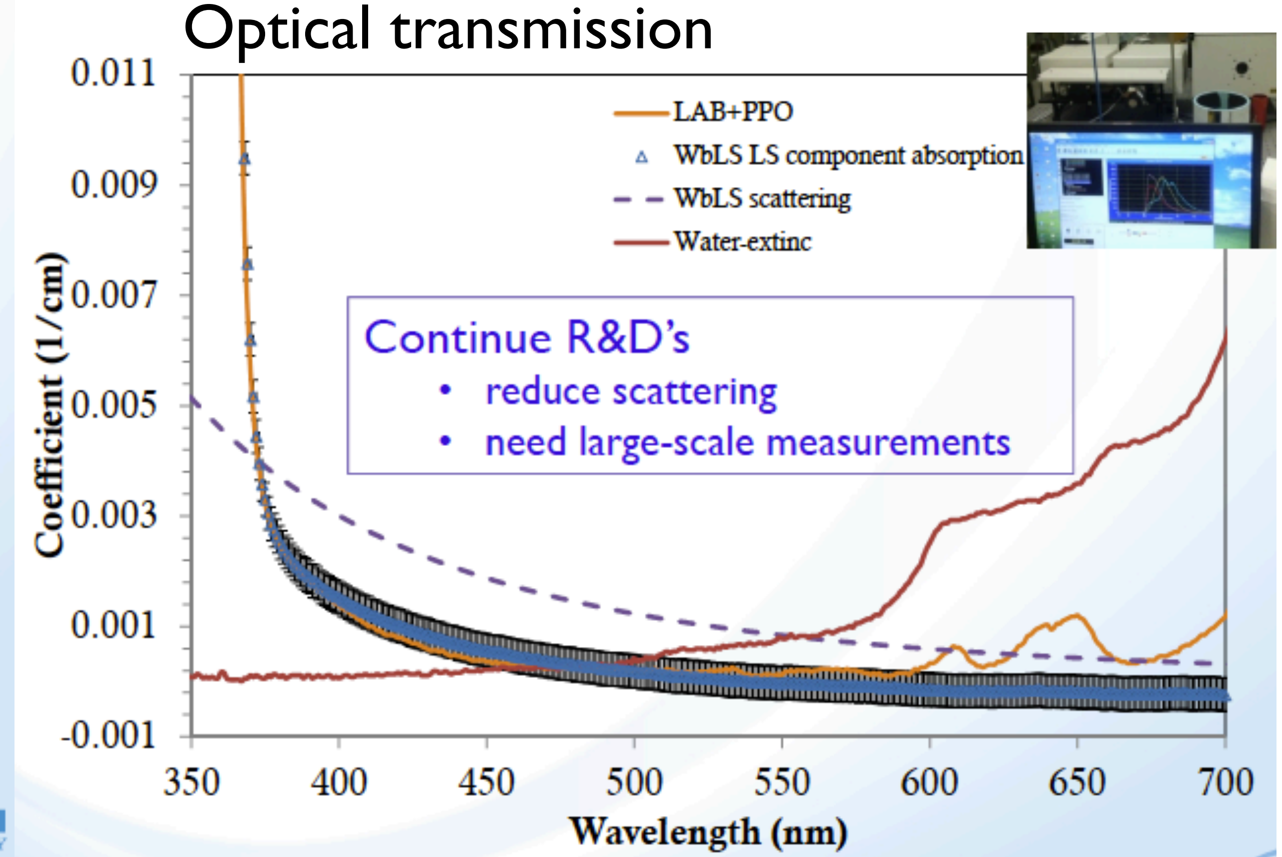
Scintillator development

The development of new scintillator materials and doping agents has proven critical to the advancement of neutrino detector design. The new water based liquid scintillator (WbLS) in particular could enable a massive detector with a broad physics program at relatively low cost. Development of these materials is a critical step for future experiments, including optimization and characterization of the WbLS cocktail for different physics goals, large-scale attenuation measurements, and light yield studies at both low and high energy.

Water-based liquid scintillator



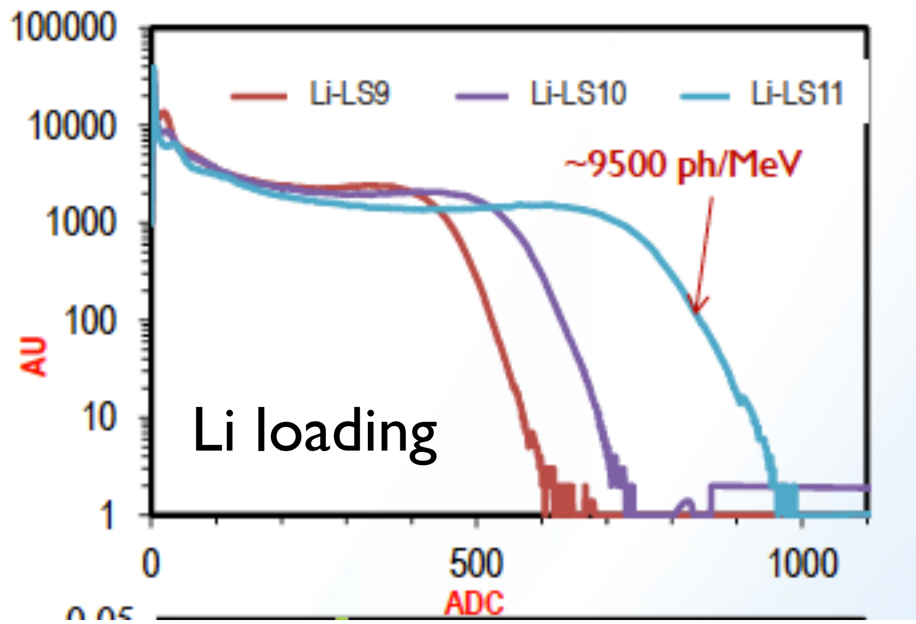
Optical transmission

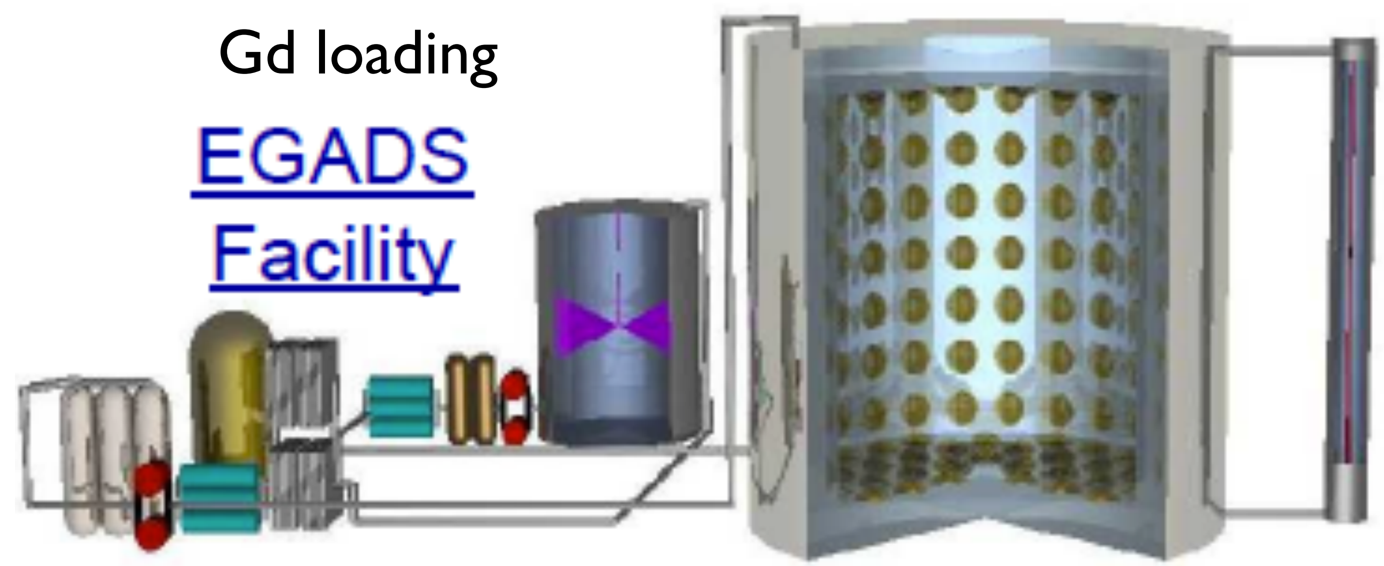


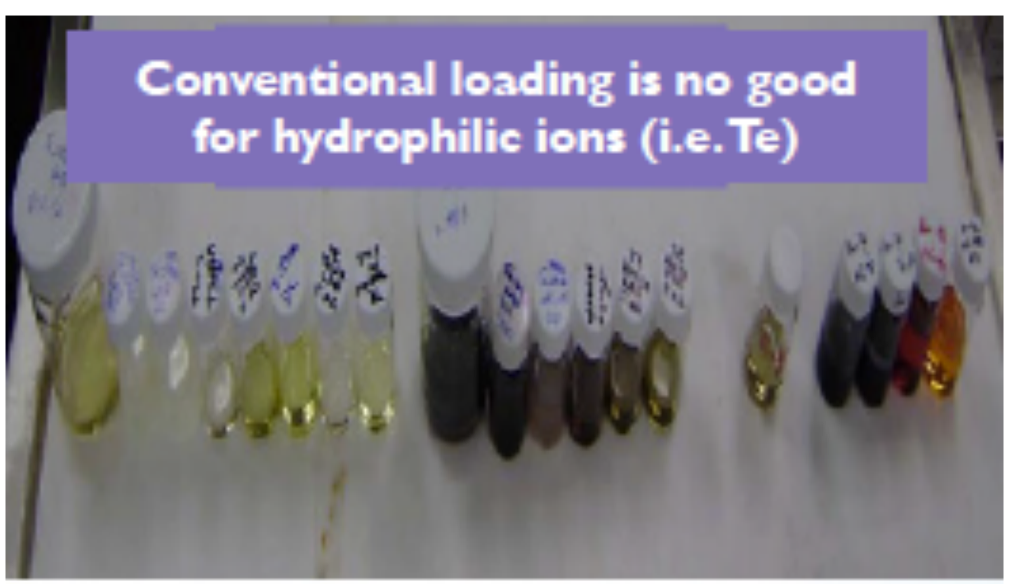
Experiments: SNO+, WATCHMAN-II

Isotope loading

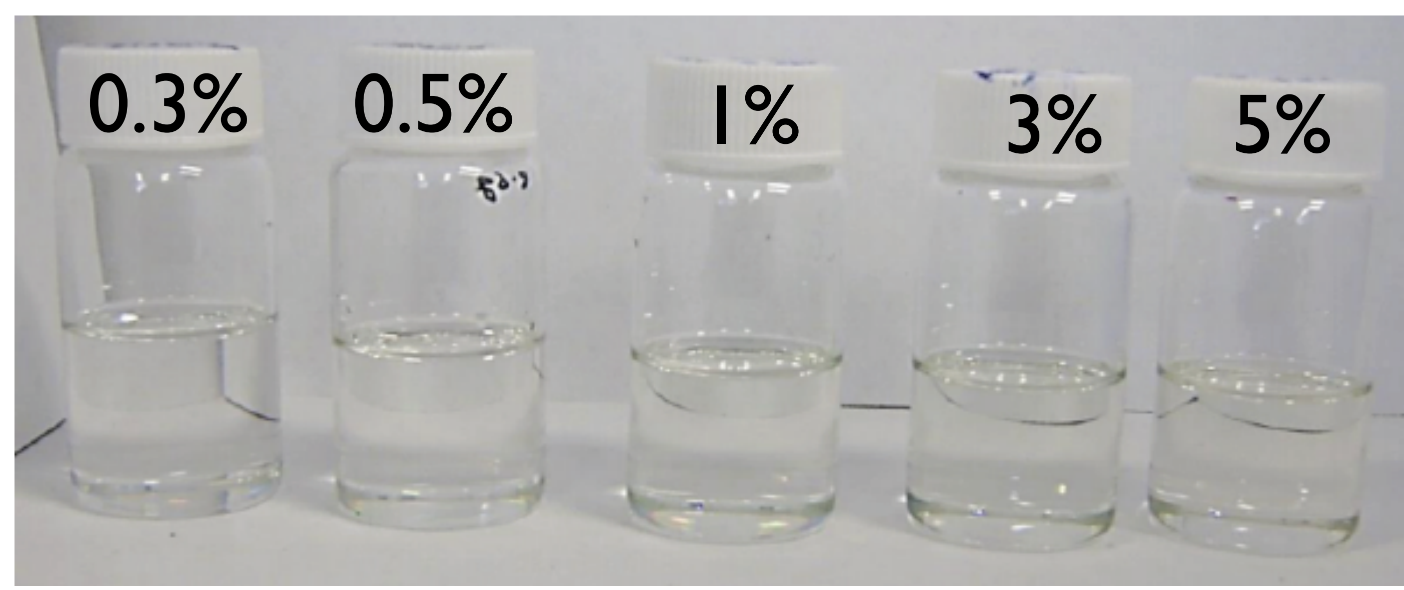
Isotope loading in traditional liquid scintillator, Gadolinium doping for water detectors, and the potential to load metallic isotopes in WbLS broaden the potential physics program and enhances the sensitivity of these experiments significantly.







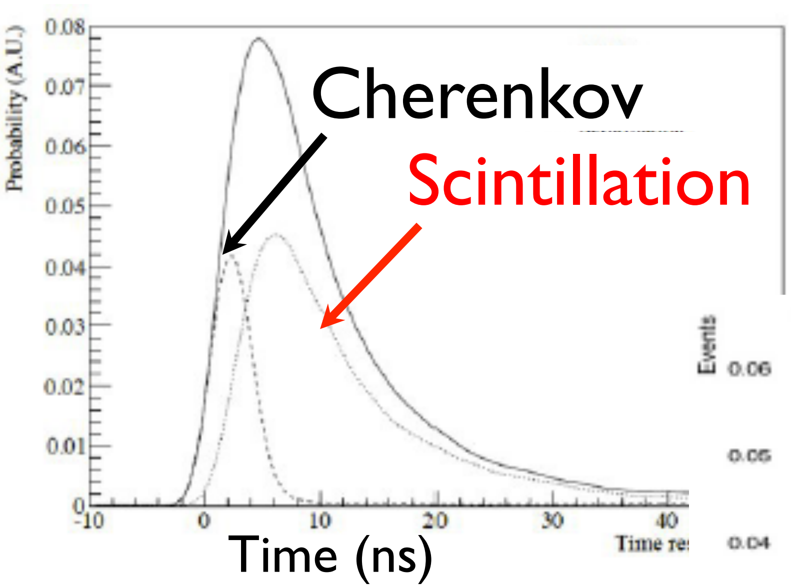
Te loading

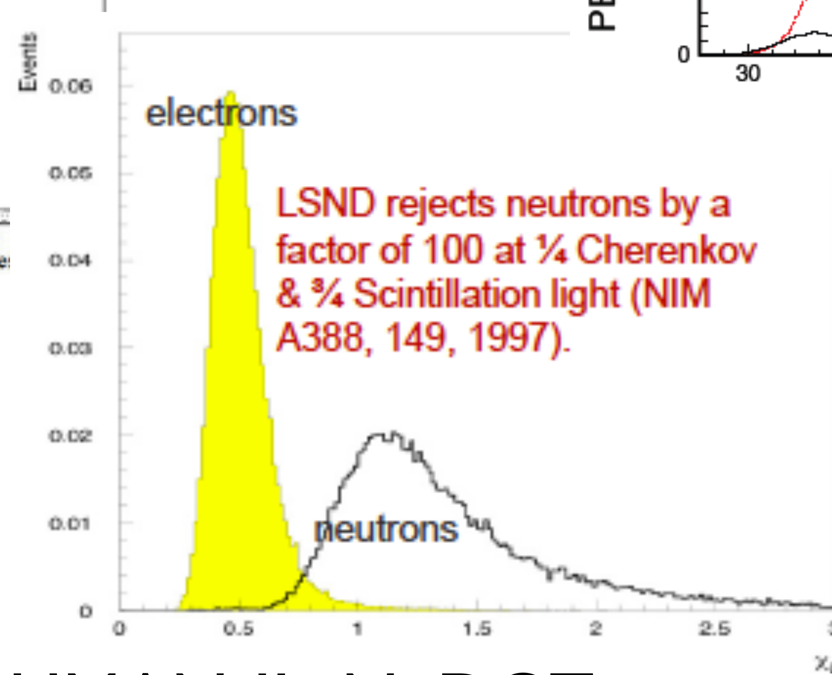


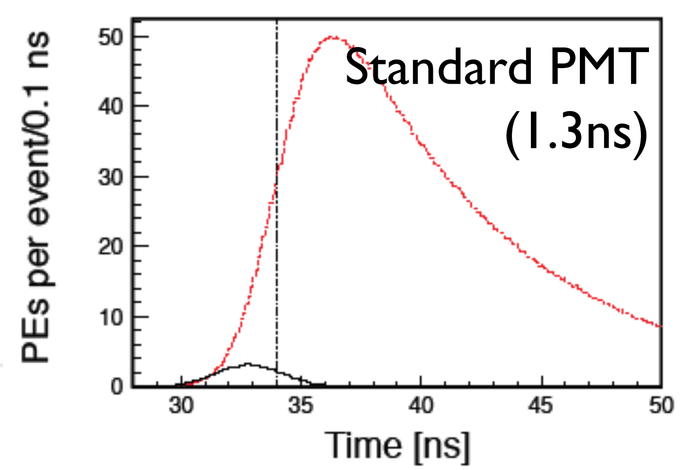
Experiments: SNO+, WATCHMAN-II, EGADS, ANNIE

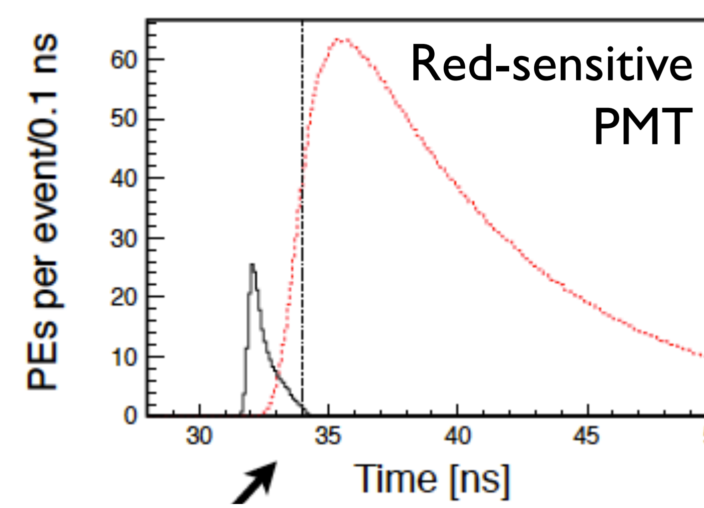
Cherenkov / scintillation separation

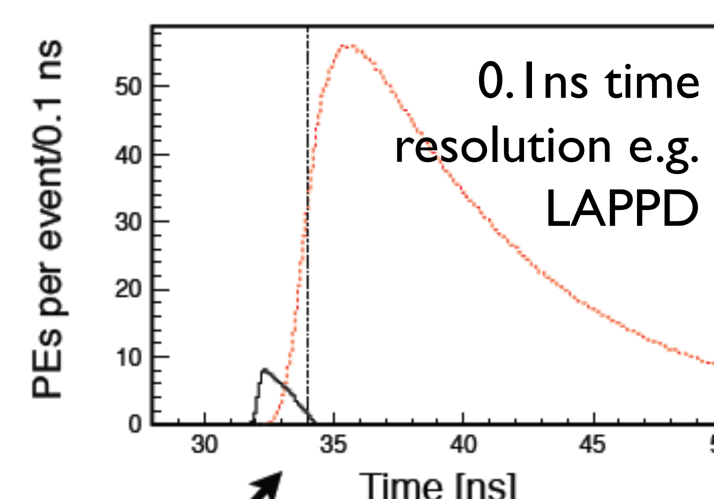
Separation of fast, directional Cherenkov light from the slower yet far more abundant isotropic scintillation light would enable astonishing advances in signal identification and background rejection capabilities via particle identification. This potential capability should be explored via both optimization of the WbLS target, and alternate photon detection methods. The ability to reconstruct event energy and direction needs to be demonstrated both theoretically (in simulation) and in practice (in smaller scale experiments).











Experiments: WATCHMAN-II, NuDOT

Purification

Large water Cherenkov and (water-based) scintillator detectors require very high purity target liquids. Purification techniques for water are well understood in industry and need no R&D, but if additives are used (either isotope loading or a scintillator component) then the process will need to be modified.

Addition of LS reduces biological growth

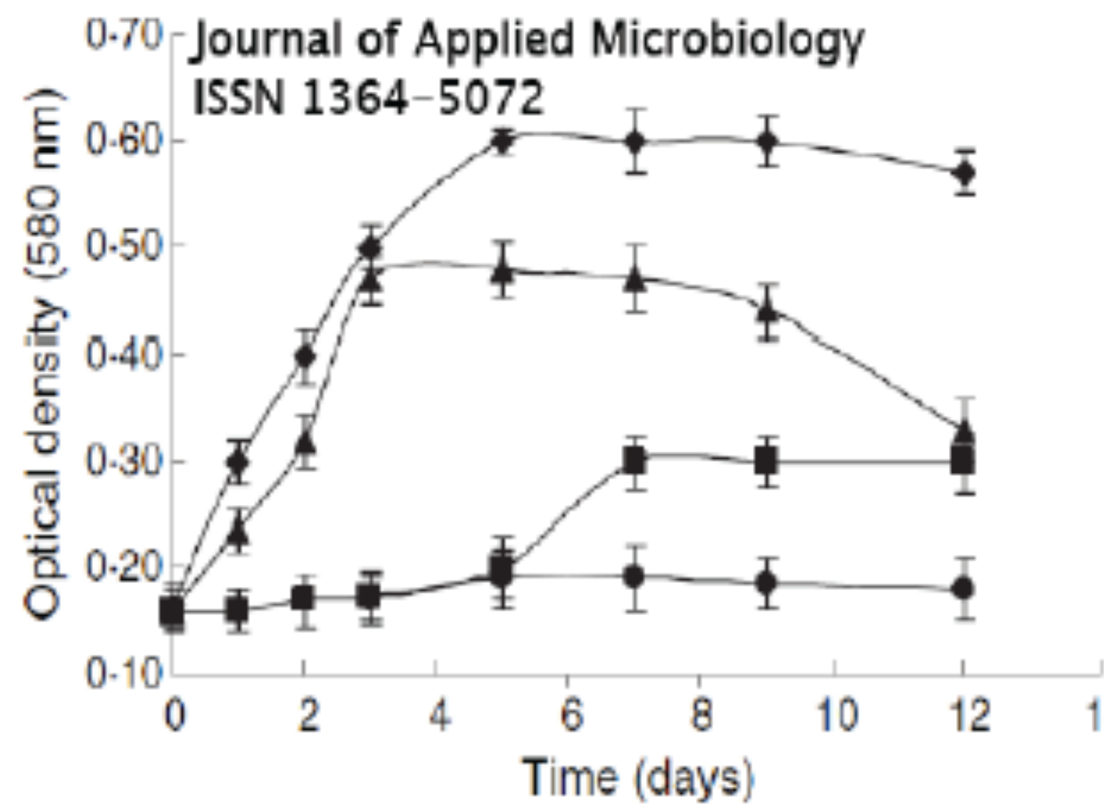
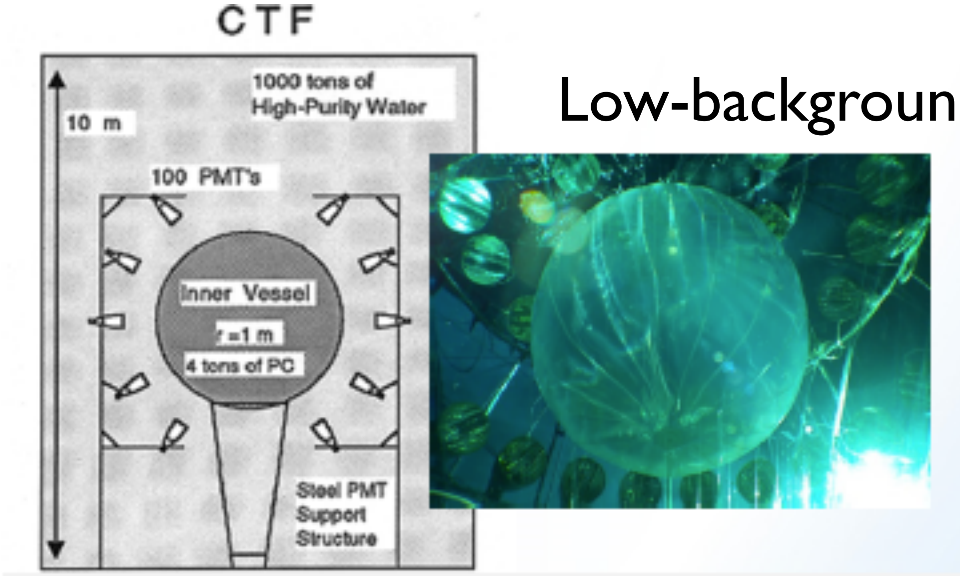


Figure 5 Time-course analysis of consortium growth at different linear alkylbenzene sulfonate concentrations (in mg l^{-1}): (◆) 10; (▲) 20; (■), 50; and (●) 100. Values are means ± standard deviations for three replicates.

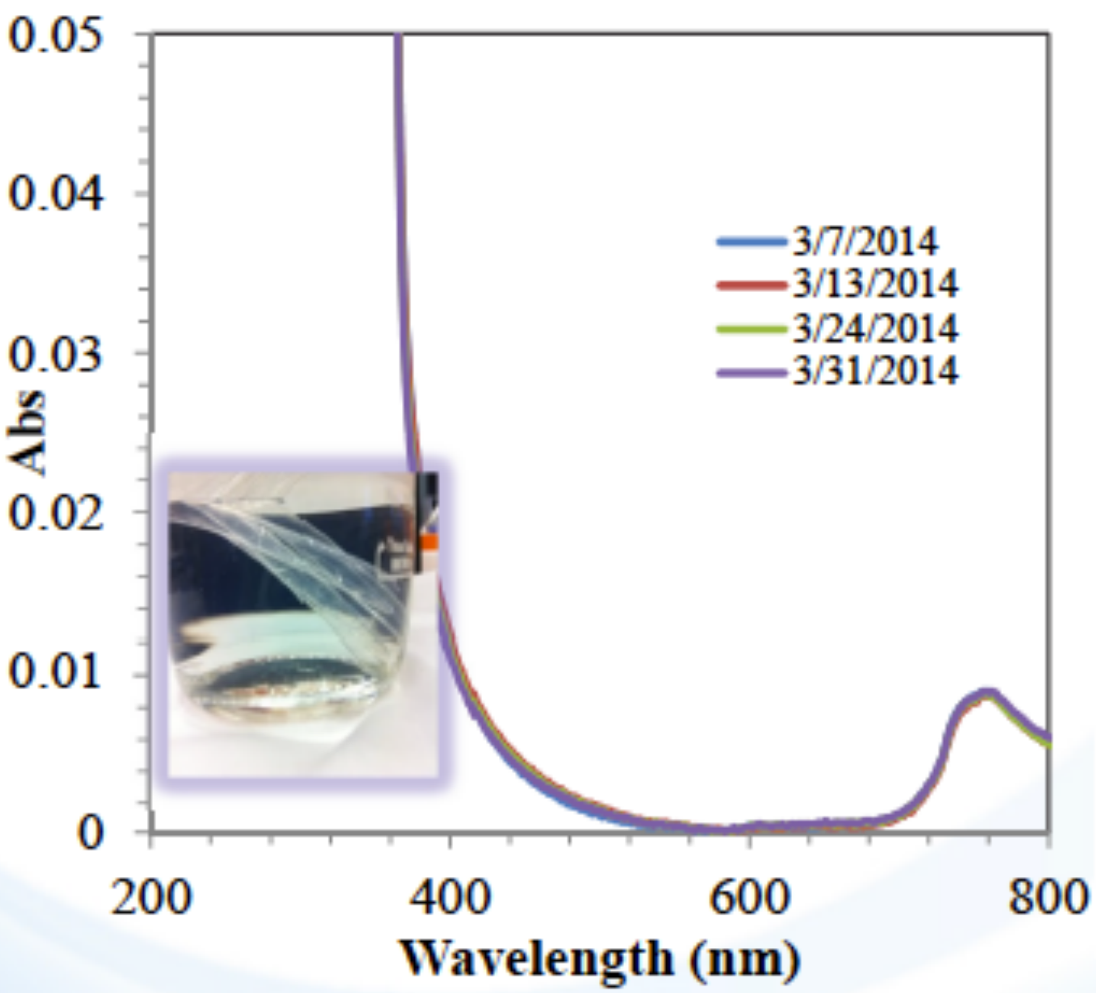
Low-background screening



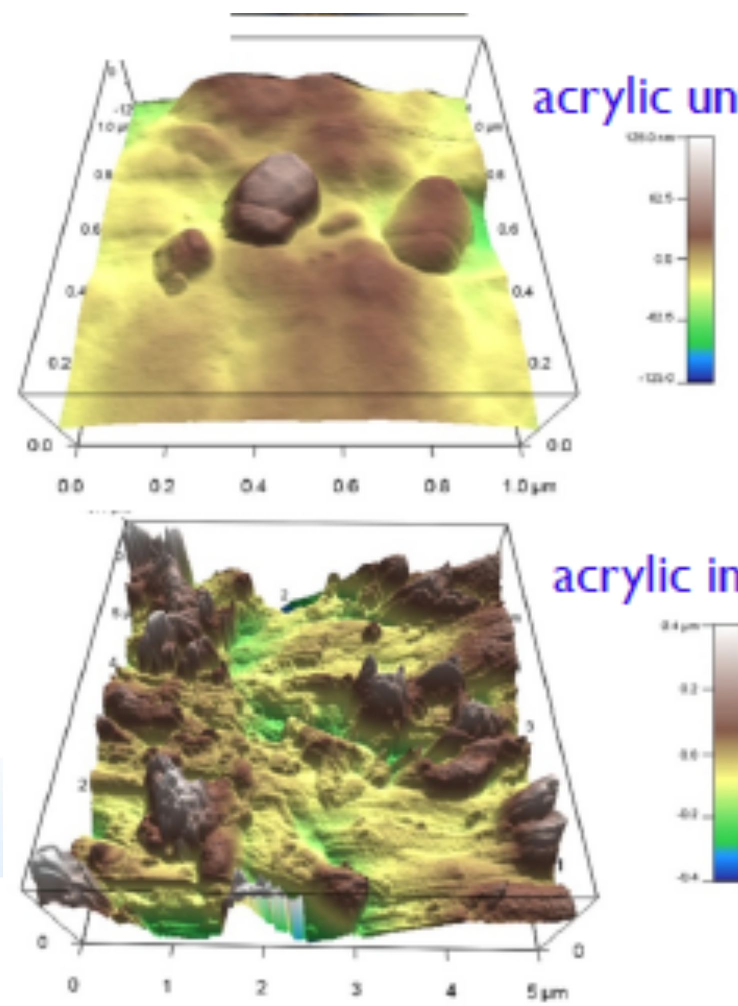
Experiments: WATCHMAN-II

Materials Compatibility

Materials placed in water or (water-based) scintillator can impact the purity and the detector efficiency. A program to determine suitable materials must exist for future water and (water-based) scintillator detectors.



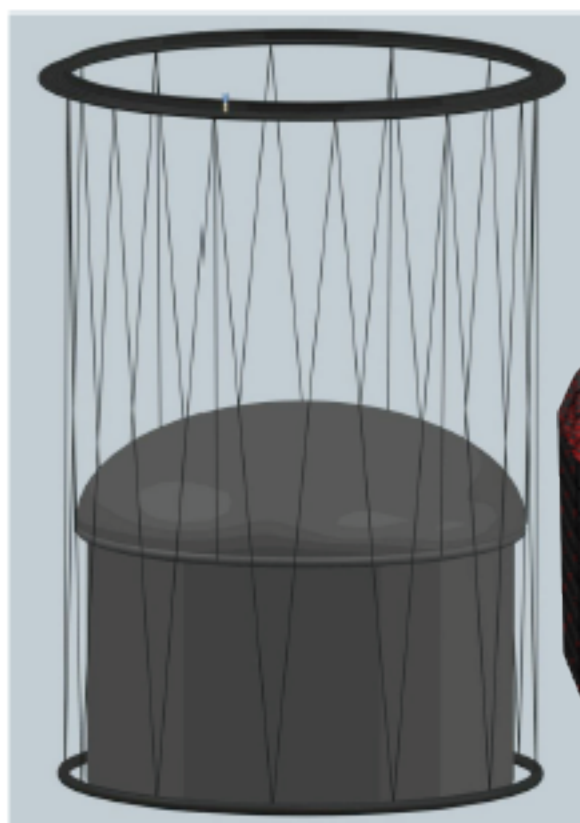
10% WbLS stable in acrylic, PP, PFA, etc

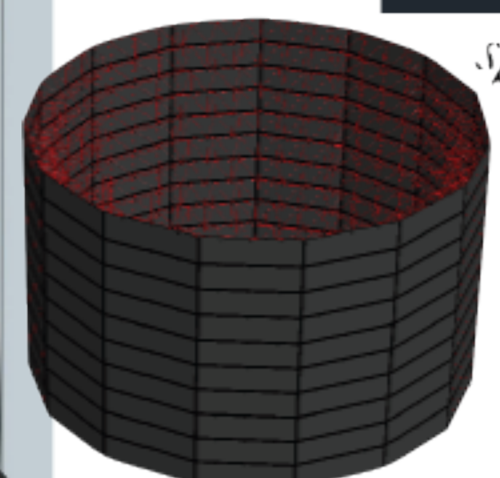


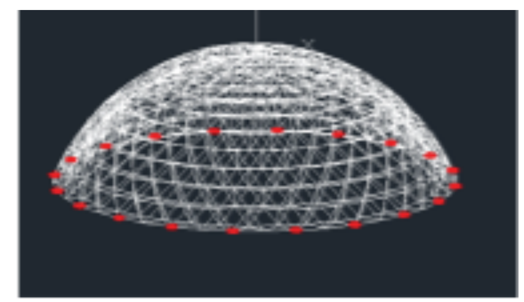
Atomic Force Microscopy (AFM)

Cost Effective Construction

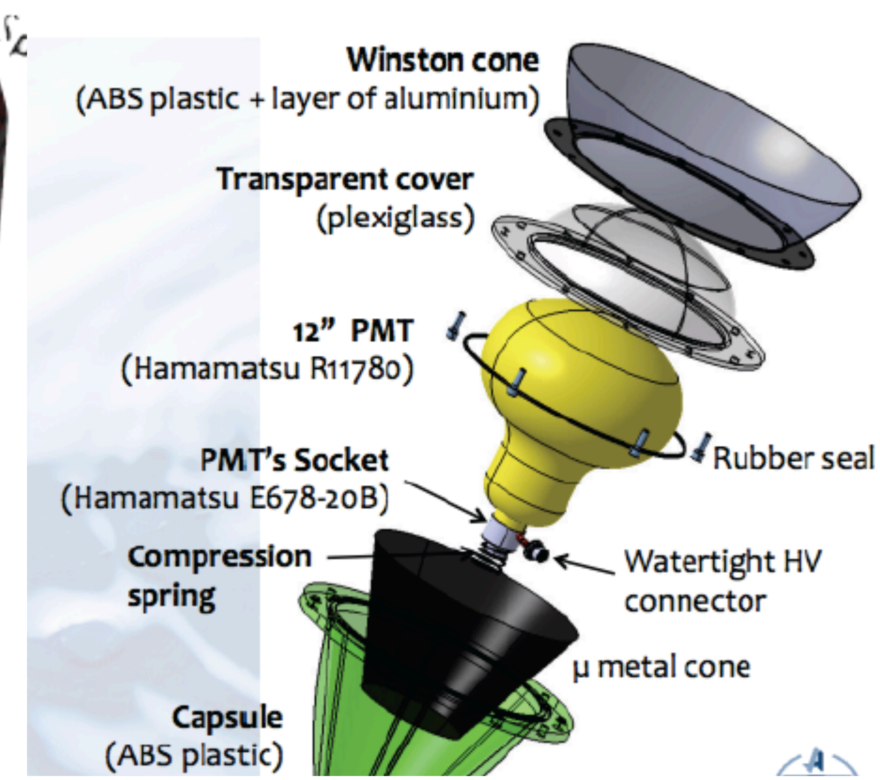
Water-based detectors (including WbLS) have the advantage of a low cost detector medium allowing very large-scale experiments. Future experiments will be limited by the cost and excavation techniques for the cavern needed to house the experiments. R&D to find lower-cost construction methods, including PMT deployment and readout techniques, can facilitate next generation neutrino detectors.







"Spaceframe"



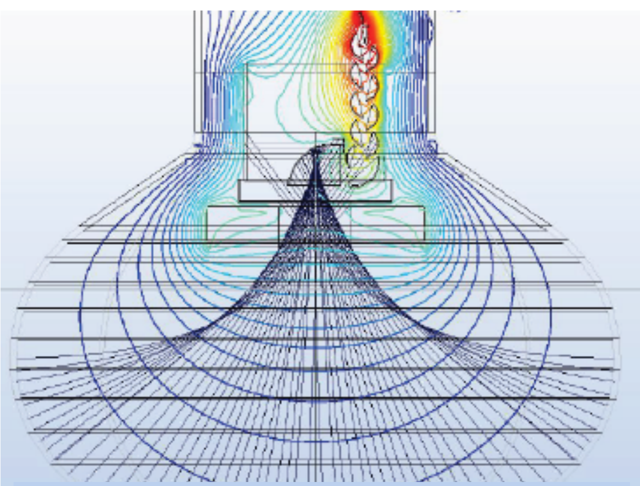
Submerged detector (natural shielding)

Experiment: CHIPS

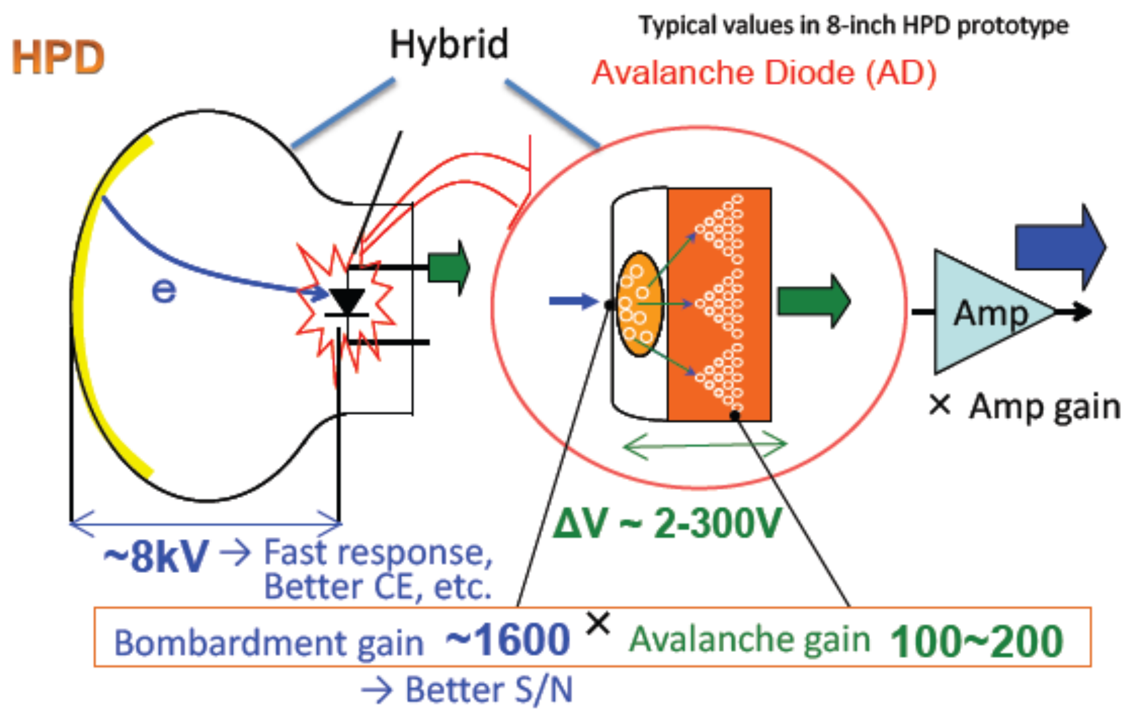
PMT modules, pressure housing

Photon Detection

A driving cost and critical performance factor in large-scale water or scintillator detectors is the photomultiplier tubes. R&D to produce cost effective, large area, fast photon detectors is important for the neutrino community. Correspondingly fast, high precision readout will be critical to take advantage of developments in photon detector technology.

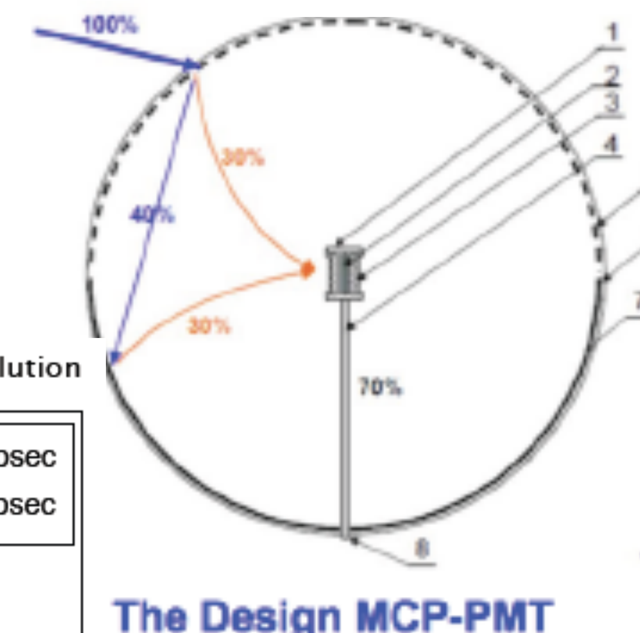


Conventional PMTs

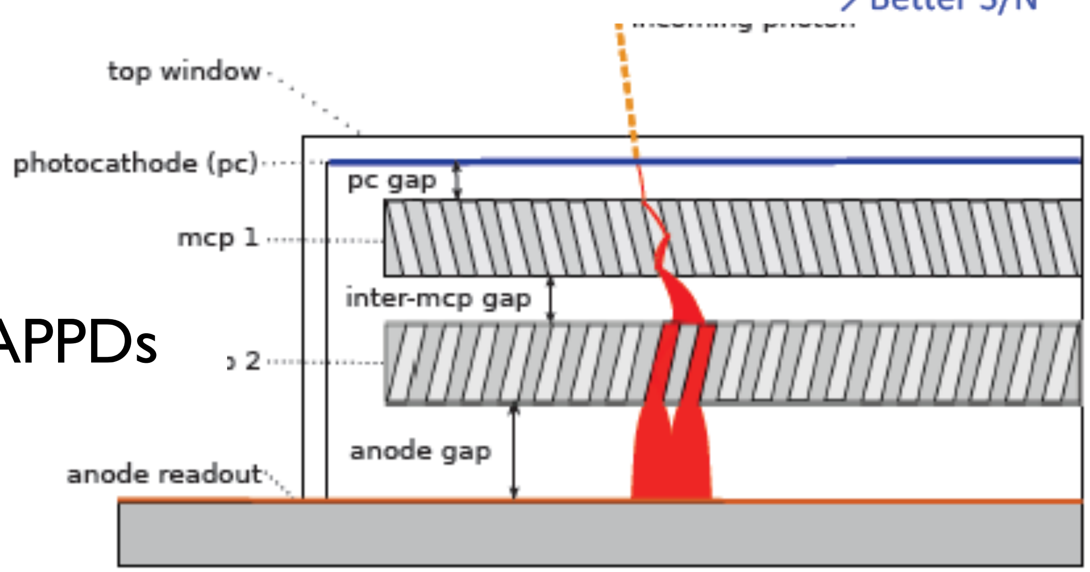


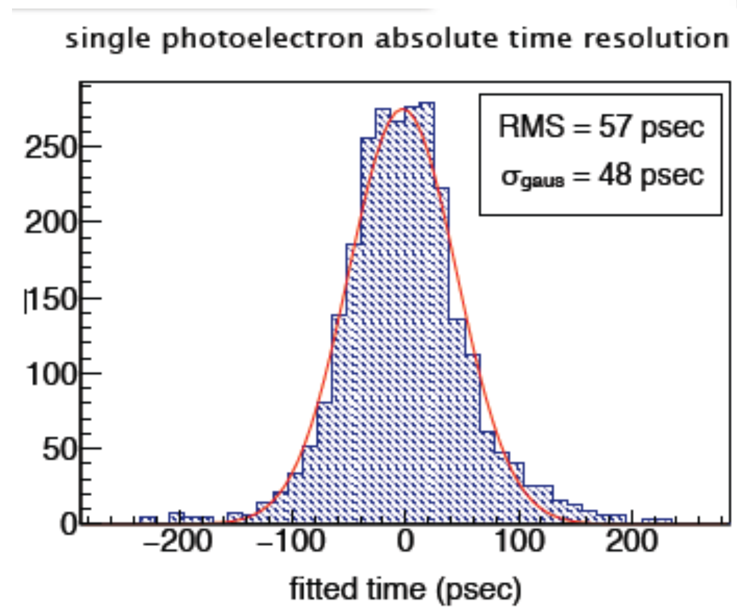
Solid-state gain stage

MCP-PMT

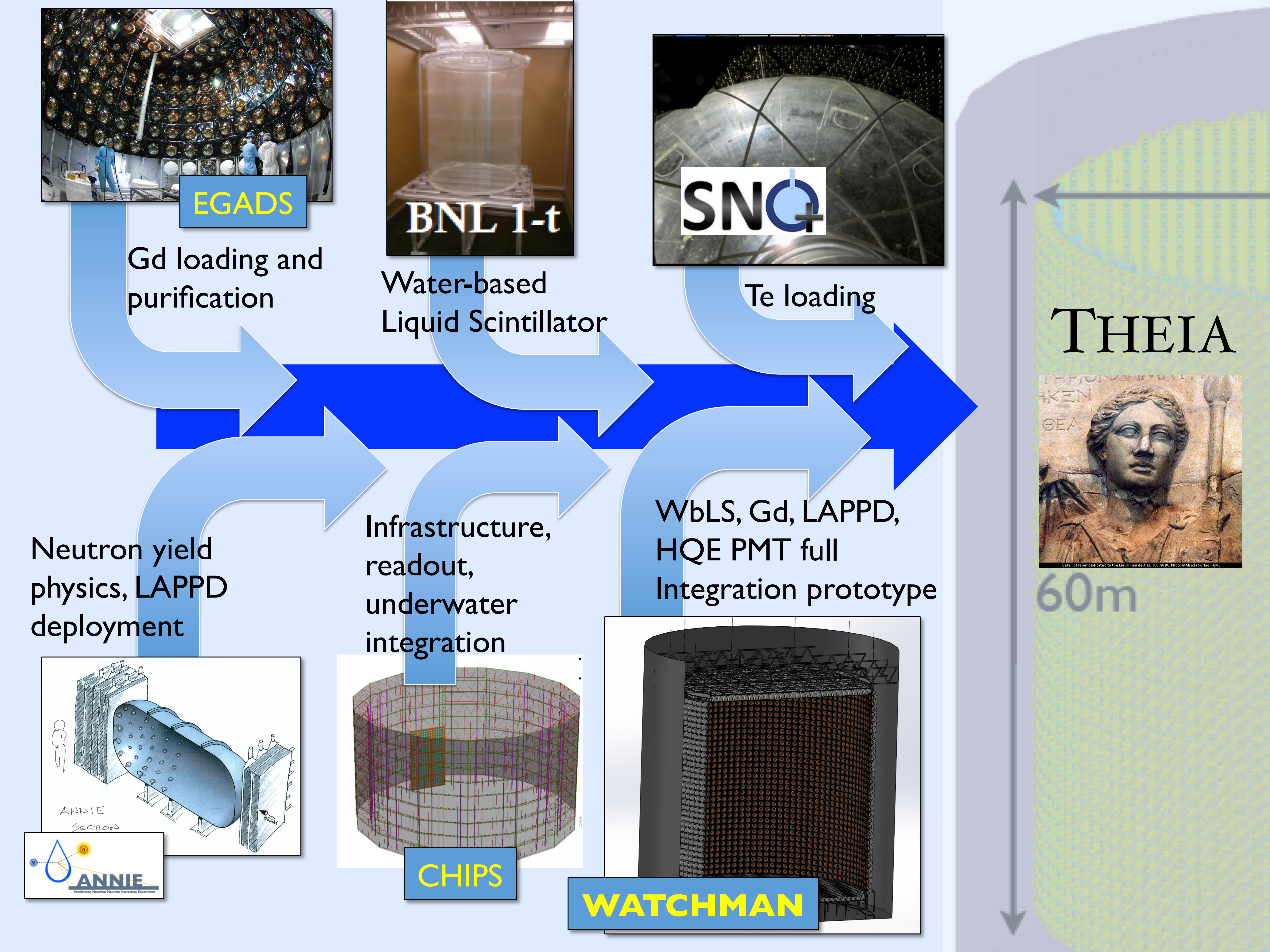


LAPPDs





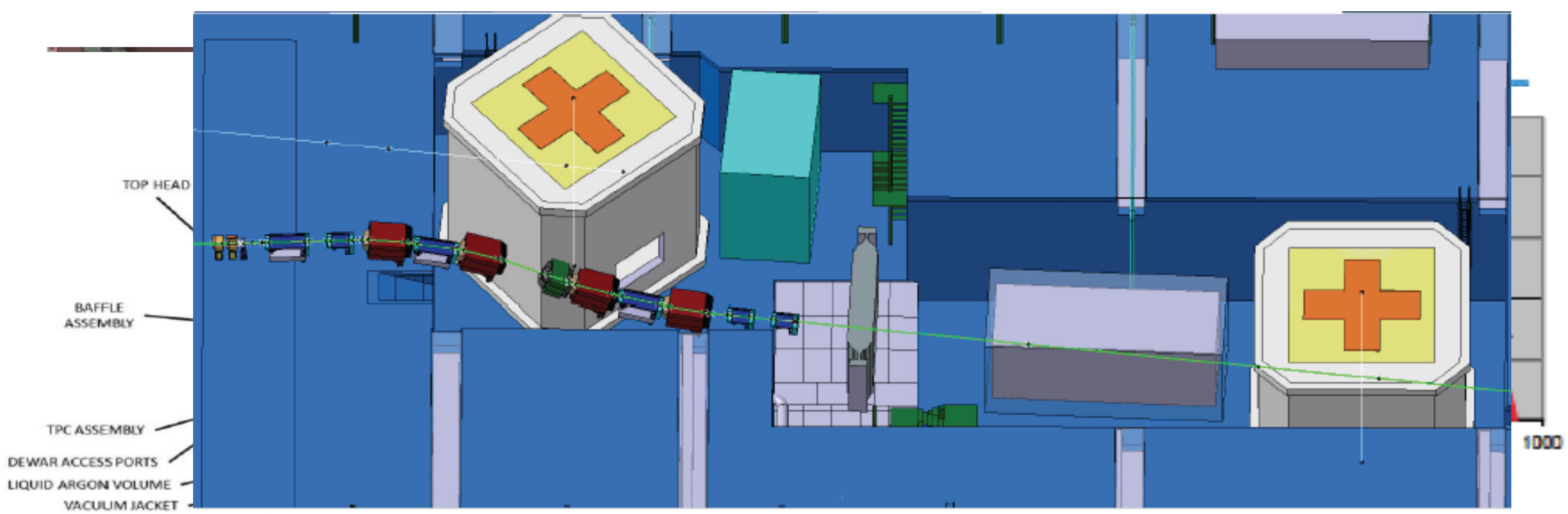
Experiments: ANNIE, WATCHMAN-II


EGADS
Gd loading and purification
BNL 1-t
Water-based Liquid Scintillator
SNO+
Te loading
THEIA
60m
Neutron yield physics, LAPPD deployment
ANNIE SECTION
ANNIE
Infrastructure, readout, underwater integration
CHIPS
WbLS, Gd, LAPPD, HQE PMT full Integration prototype
WATCHMAN

LArTPC Testbeam

A comprehensive test beam program must be performed to characterize present and future LAr TPCs. This program should include:

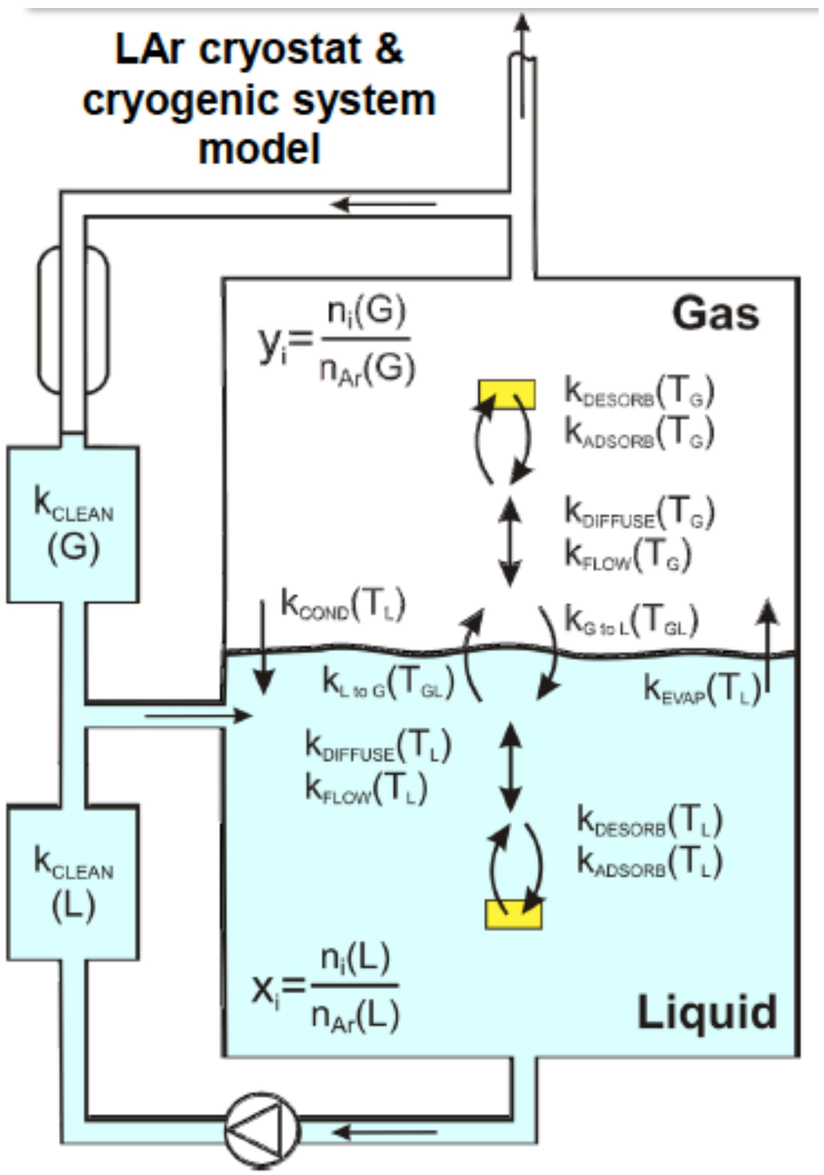
- Electromagnetic and hadronic showers measurements
- Charged particle energy deposition
- Neutron cross section measurements



Experiments: LArIAT, CERN Platform, Captain

Liquid Argon Purity

The process of contamination generation and transport inside the large liquid argon detectors is not well understood. A program of measurements to study the sources of electronegative and light-quenching contamination in LAr detectors and the migration of contaminates throughout the detector systems is needed to insure the future detector design will meet specifications.



Water Desorption by FR4

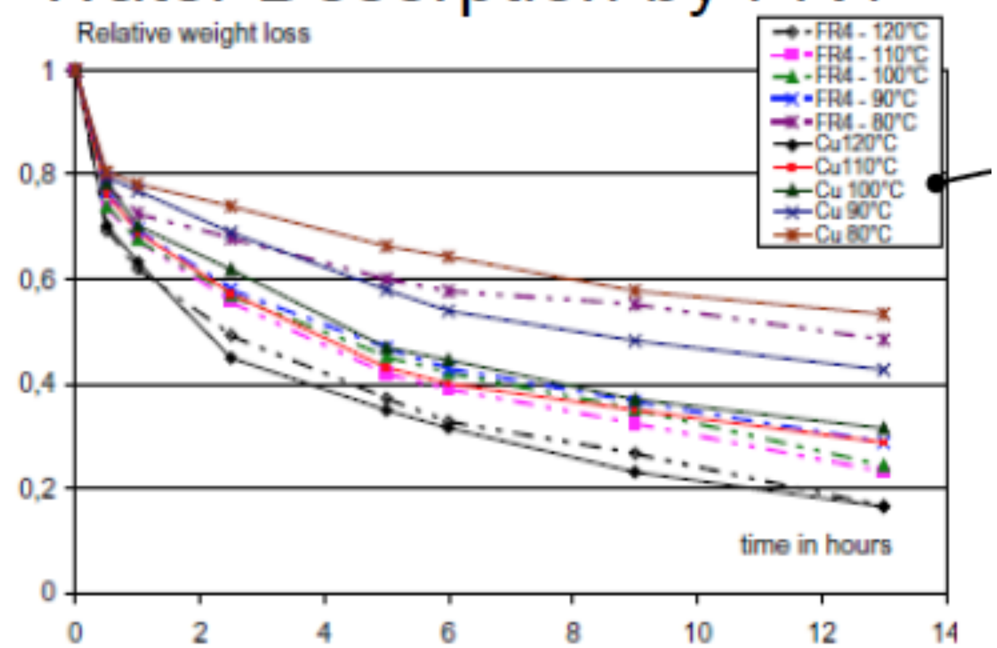


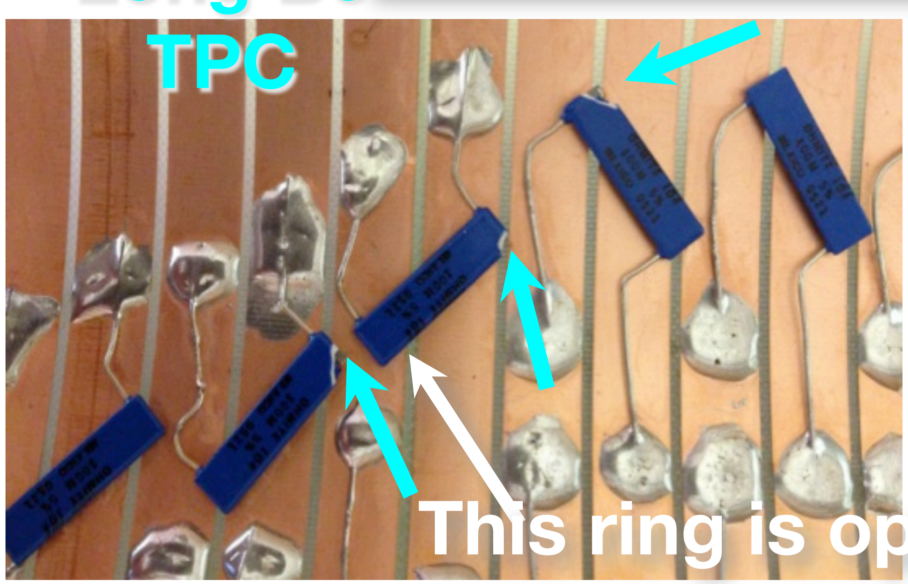
Fig. 3. Relative weight loss for 2 epoxy based PCBs at different temperatures.

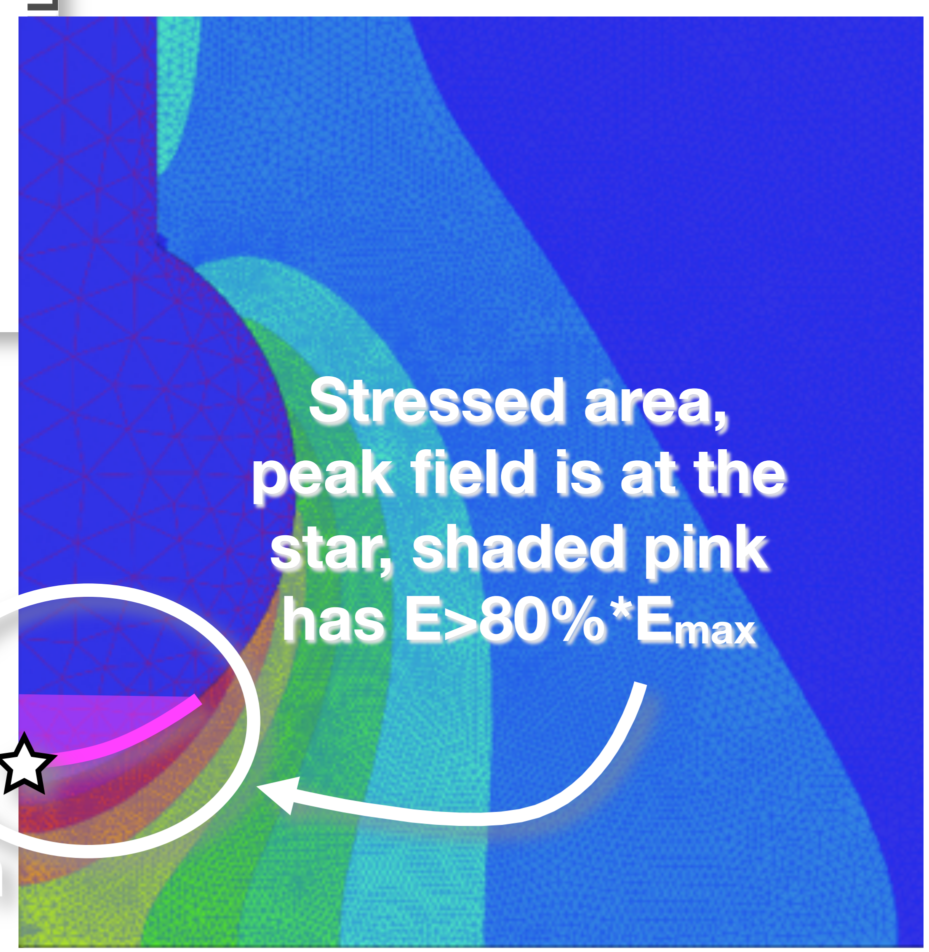
Measurements of the physical properties of LAr ar important

Experiments: LArIAT, CERN Platform, Captain, SBN

High Voltage Breakdown

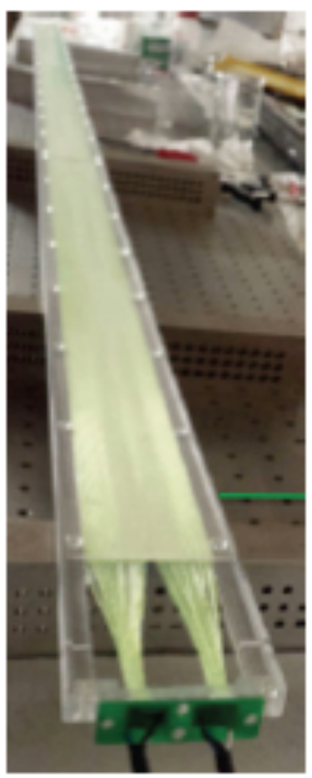
R&D on the generation and breakdown of high voltage will reduce the risk to future LAr detectors and could lead to more monolithic and lower cost detector designs based on longer drifts.





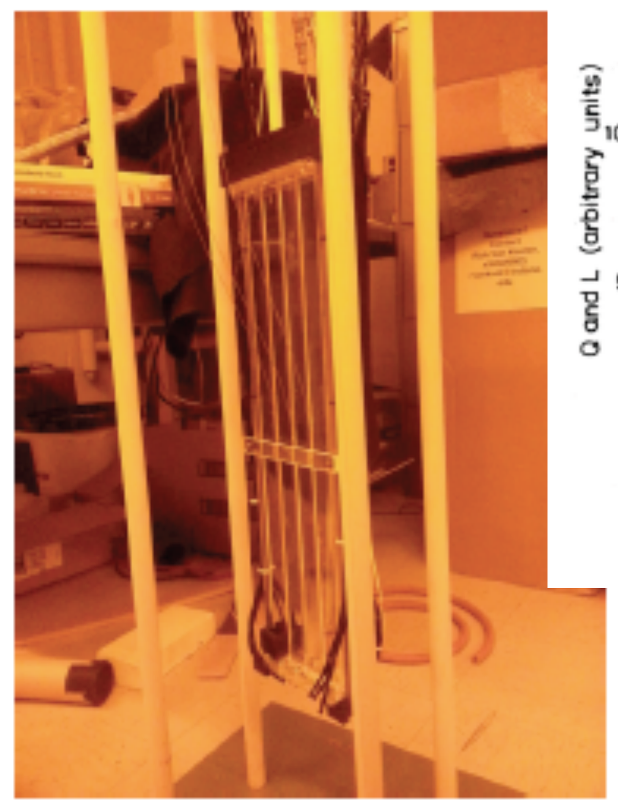
Photon Detection in LAr

Present photon detector designs capture a very small fraction of the scintillation light generated in the LAr detectors. Detectors with better efficiency should be developed.

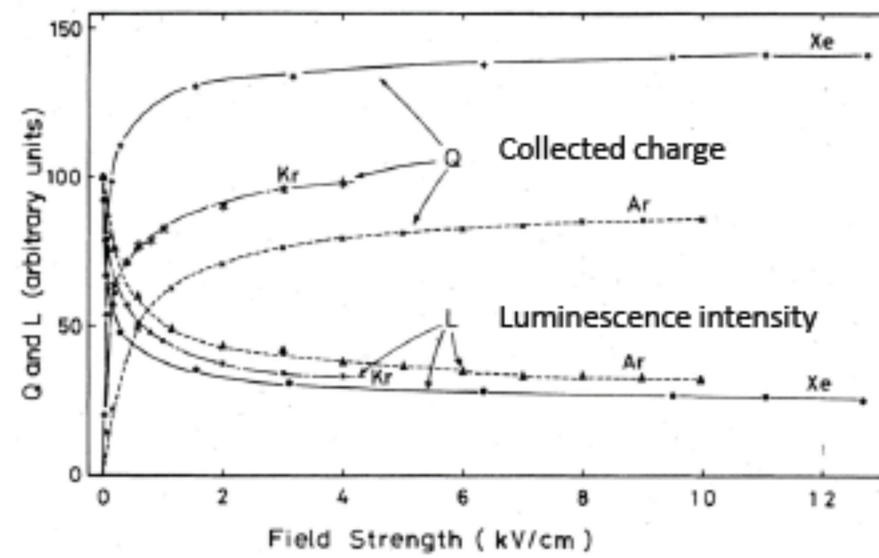


CSU

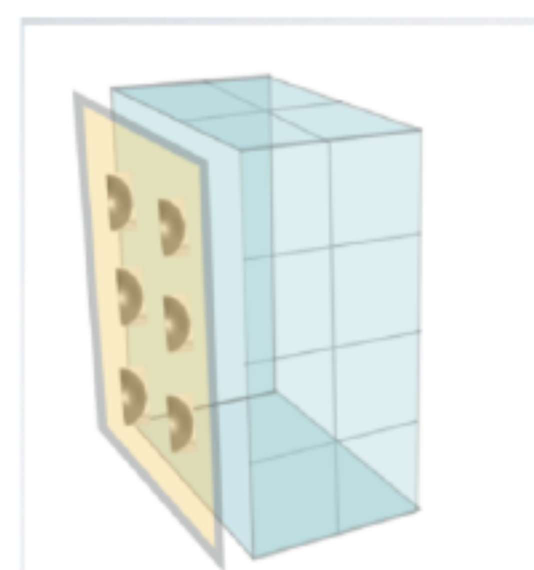
LSU



IU



S. Kubota et al., Phys. Rev. B, 20, 8 (1979)



Experiments: LArIAT, CERN Platform, Captain, SBN

Electronics Development

- ASICs at, or near, PMTs will result in better time response and higher S/N for water detector PMT arrays. Significantly lower PM gain will result in better linearity, longer PMT life and reduced after pulsing.
- For separation of fast, directional Cherenkov light from the slower isotropic scintillation light, waveform recording becomes a tool to enable improved signal identification and background rejection. Sampling frequency in the range of a few Gsps (e.g., ~4Gsps) becomes necessary.
- Charge readout electronics R&D for noble liquid TPCs
  - A digital ASIC must be developed to provide multiplexing and data transmission. This is necessary for the ELBNE designs which the US has studied.
  - Front end ASIC and ADC ASIC should be further optimized for optimal system design.
- R&D on cold readout electronics design with different electrode configurations to reduce ambiguities in reconstruction, e.g., a finer segmentation planar anode, should be explored.
- Development of electronics to read out large arrays of SiPMs efficiently is necessary for LAr photon detection.
  - R&D will have to address photon detectors (primarily SiPMs), wavelength shifters and cold front electronics as a closely coupled system, optimized for different TPC geometries.
  - In near-the-surface detectors, where beam time structure may be used to reduce the cosmic ray background, waveform recording may become necessary

Summary

- Opportunities for R&D to have a major impact on near and far term experiments abound.
- A strong R&D portfolio is critical to the health and strength of the intermediate and future of the neutrino program.
- The selected topics focus on the issues which would have major impact future experiments.
- Optimizing the synergy between the SBN, Ongoing R&D, ELBNF, and the intermediate program is critical to get the maximum benefit from the limited resources.

BACKUP

Planned Demonstrations

Site	Scale	Target	Measurements	Timescale
UChicago	bench top	H2O	fast photodetectors	Exists
CHIPS	10 kton	H2O	electronics, readout, mechanical infrastructure	2019
EGADS	200 ton	H2O+Gd	isotope loading, fast photodetectors	Exists
ANNIE	30 ton			2016
WATCHMAN	1 kton			2018
UCLA/MIT	1 ton	LS	fast photodetectors	2015
Penn	30 L	(Wb)LS	light yield, timing, loading	Exists
SNO+	780 ton			2016
LBNL	bench top	WbLS	light yield, timing, cocktail optimization, loading, attenuation, reconstruction	Early 2015
BNL	1 ton			Summer 2015
WATCHMAN-II	1 kton			2019